

What is claimed is:

1. In a defibrillator, a shocking circuit comprising:
a set of capacitors; and
switching circuitry connected to the capacitors and operative to selectively discharge the capacitors so as to generate a first phase of a defibrillation pulse waveform wherein the first phase of the waveform has at least three distinct voltage peaks.
2. The shocking circuit of claim 1 wherein the set of capacitors comprises first, second and third capacitors.
3. The shocking circuit of Claim 2, wherein the switching circuitry is operative to:
generate a first step of the pulse waveform by discharging the capacitors while the first, second and third capacitors are connected in parallel;
generate a second step of the pulse waveform by discharging the capacitors while the first and second capacitors are connected in parallel and the third capacitor is connected in series; and
generate a third step of the pulse waveform by discharging the capacitors while the first, second and third capacitors are connected in series.
4. The shocking circuit of Claim 3, wherein the switching circuitry is operative to selectively discharge the capacitors during the three steps of the pulse waveform for respective first, second and third time periods selected to maximize a final myocardial voltage within myocardial tissue receiving the pulse waveform.

5. The shocking circuit of Claim 4, wherein the first, second and third time periods are represented, respectively, by:

$$\alpha_1^{opt} = -\frac{\tau_m}{\alpha_1} \cdot \ln \left\{ \left(\frac{\tau_m}{\tau_{s1}} \right) \left(\frac{2 - \frac{\alpha_2}{\alpha_1}}{1 - \frac{\alpha_2}{\alpha_1}} \right) \right\};$$

$$d_2^{opt} = +\frac{\tau_m}{\alpha_2} \cdot \ln \left\{ \left(\frac{1}{2} \right) \left(\frac{2 - \frac{\alpha_2}{\alpha_1}}{1 - \frac{\alpha_2}{\alpha_1}} \right) \left(\frac{1 - \frac{\alpha_3}{\alpha_2}}{K_C - \frac{\alpha_3}{\alpha_2}} \right) \right\}; \text{ and}$$

5 $d_3^{opt} = -\frac{\tau_m}{\alpha_3} \cdot \ln \left\{ \left(K_C \right) \left(\frac{1 - \frac{\alpha_3}{\alpha_2}}{K_C - \frac{\alpha_3}{\alpha_2}} \right) \right\}; \text{ wherein}$

$$K_C = 1 + (C_C) / (C_A + C_B + C_C);$$

$$\alpha_1 = 1 - (\tau_m / \tau_{s1}), \alpha_2 = 1 - (\tau_m / \tau_{s2}), \text{ and } \alpha_3 = 1 - (\tau_m / \tau_{s3});$$

$$\tau_{s1} = R_s \cdot C_{s1}; \tau_{s2} = R_s \cdot C_{s2}; \text{ and } \tau_{s3} = R_s \cdot C_{s3};$$

$$C_{s1} = C_A + C_B + C_C;$$

10 $C_{s2} = [(C_A + C_B) \cdot (C_C)] / [C_A + C_B + C_C];$

$$C_{s3} = 1 / \left[\frac{1}{C_A} + \frac{1}{C_B} + \frac{1}{C_C} \right];$$

C_A , C_B , & C_C are the respective capacitances of the first, second and third capacitors; and

τ_m is a predetermined myocardial tissue time constant.

15 6. The shocking circuit of Claim 2, wherein the capacitance of the capacitors are selected so as to minimize the amount of energy to be stored in the capacitors while maximizing a final myocardial voltage within myocardial tissue receiving the pulse waveform.

FIG. 6 is a graph of the voltage across the capacitors as a function of time.

7. The shocking circuit of Claim 6, wherein capacitances of the first, second and third capacitors are represented, respectively, by:

$$C_A^{opt} = 0.6673 \cdot \left(\frac{\tau_m}{R_s} \right);$$

$$C_B^{opt} = 0.6673 \cdot \left(\frac{\tau_m}{R_s} \right); \text{ and}$$

5 $C_C^{opt} = 1.5356 \cdot \left(\frac{\tau_m}{R_s} \right); \text{ wherein}$

R_s is a predetermined system resistance; and

τ_m is a predetermined myocardial tissue time constant.

8. The shocking circuit of Claim 6, wherein the capacitances of the first, second and third capacitors are represented, approximately,
10 by:

$$C_A^{opt} = \left(\frac{2}{3} \right) \cdot \left(\frac{\tau_m}{R_s} \right);$$

$$C_B^{opt} = \left(\frac{2}{3} \right) \cdot \left(\frac{\tau_m}{R_s} \right); \text{ and}$$

$$C_C^{opt} = \left(\frac{3}{2} \right) \cdot \left(\frac{\tau_m}{R_s} \right).$$

9. The shocking circuit of Claim 6, wherein the switching
15 circuitry is operative to selectively discharge the capacitors during the three steps of the pulse waveform for respective first, second and third time periods.

10. The shocking circuit of Claim 9, wherein the first, second and third time periods are represented, respectively, by:

20 $d_1^{opt} = 0.878 \cdot \tau_m;$

$$d_2^{opt} = 0.277 \cdot \tau_m; \text{ and}$$

$$d_3^{opt} = 0.200 \cdot \tau_m; \text{ wherein}$$

τ_m is a predetermined myocardial tissue time constant.

11. In a defibrillator having a set of capacitors, a method for generating a shocking pulse comprising:
charging the capacitors; and
selectively discharging the capacitors so as to generate a first phase of a defibrillation pulse waveform wherein the first phase of the waveform has at least three distinct voltage peaks.

12. The method of Claim 11 for use in a shocking circuit having first, second, and third capacitors and wherein selectively discharging the capacitors comprises:
generating a first step of the pulse waveform by discharging the capacitors while the first, second and third capacitors are connected in parallel;
generating a second step of the pulse waveform by discharging the capacitors while the first and second capacitors are connected in parallel and the third capacitor is connected in series; and
generating a third step of the pulse waveform by discharging the capacitors while the first, second and third capacitors are connected in series.

13. The method of Claim 12, wherein discharging the capacitors to generate the first, second and thirds steps of the pulse waveform are respectively performed for first, second and third time periods selected to maximize a final myocardial voltage within myocardial tissue receiving the pulse waveform.

14. The method of Claim 13, wherein the first, second and third time periods are represented, respectively, by:

$$d_1^{opt} = -\frac{\tau_m}{\alpha_1} \cdot \ln \left\{ \left(\frac{\tau_m}{\tau_{s1}} \right) \left(\frac{2 - \frac{\alpha_2}{\alpha_1}}{1 - \frac{\alpha_2}{\alpha_1}} \right) \right\};$$

$$d_2^{opt} = +\frac{\tau_m}{\alpha_2} \cdot \ln \left\{ \left(\frac{1}{2} \right) \left(\frac{2 - \frac{\alpha_2}{\alpha_1}}{1 - \frac{\alpha_2}{\alpha_1}} \right) \left(\frac{1 - \frac{\alpha_3}{\alpha_2}}{K_C - \frac{\alpha_3}{\alpha_2}} \right) \right\}; \text{ and}$$

$$d_3^{opt} = -\frac{\tau_m}{\alpha_3} \cdot \ln \left\{ \left(K_C \right) \left(\frac{1 - \frac{\alpha_3}{\alpha_2}}{K_C - \frac{\alpha_3}{\alpha_2}} \right) \right\}; \text{ wherein}$$

$$K_C = 1 + (C_C) / (C_A + C_B + C_C);$$

$$\alpha_1 = 1 - (\tau_m / \tau_{s1}), \alpha_2 = 1 - (\tau_m / \tau_{s2}), \text{ and } \alpha_3 = 1 - (\tau_m / \tau_{s3});$$

$$\tau_{s1} = R_s \cdot C_{s1}; \tau_{s2} = R_s \cdot C_{s2}; \text{ and } \tau_{s3} = R_s \cdot C_{s3};$$

$$C_{s1} = C_A + C_B + C_C;$$

$$C_{s2} = [(C_A + C_B) \cdot (C_C)] / [C_A + C_B + C_C];$$

$$C_{s3} = 1 / \left[\frac{1}{C_A} + \frac{1}{C_B} + \frac{1}{C_C} \right];$$

C_A , C_B , & C_C are the respective capacitances of the first, second and third capacitors; and

τ_m is a predetermined myocardial tissue time constant.

15. The method of Claim 12 further comprising selecting optimal capacitances for the capacitors so as to minimize the amount of energy to be stored in the capacitors while maximizing a final myocardial voltage within myocardial tissue receiving the pulse waveform.

16. The method of Claim 5, wherein the optimal capacitances of the first, second and third capacitors are represented, respectively, by:

$$C_A^{opt} = 0.6673 \cdot \left(\frac{\tau_m}{R_s} \right);$$

$$C_B^{opt} = 0.6673 \cdot \left(\frac{\tau_m}{R_s} \right); \text{ and}$$

$$C_C^{opt} = 1.5356 \cdot \left(\frac{\tau_m}{R_s} \right); \text{ wherein}$$

R_s is a predetermined system resistance; and

τ_m is a predetermined myocardial tissue time constant.

17. The method of Claim 15, wherein capacitances of the first, second and third capacitors are represented, approximately, by:

5 $C_A^{opt} = \left(\frac{2}{3}\right) \cdot \left(\frac{\tau_m}{R_s}\right);$

$C_B^{opt} = \left(\frac{2}{3}\right) \cdot \left(\frac{\tau_m}{R_s}\right); \text{ and}$

$C_C^{opt} = \left(\frac{3}{2}\right) \cdot \left(\frac{\tau_m}{R_s}\right).$

18. The method of Claim 15 further comprising selectively discharging the capacitors during the three steps of the pulse waveform for respective first, second and third time periods.

19. The method of Claim 18, wherein the first, second and third time periods are represented, respectively, by:

$d_1^{opt} = 0.878 \cdot \tau_m;$

$d_2^{opt} = 0.277 \cdot \tau_m; \text{ and}$

15 $d_3^{opt} = 0.200 \cdot \tau_m; \text{ wherein}$

τ_m is a predetermined myocardial tissue time constant.

20. In a defibrillator having first, second and third capacitors, a shocking circuit comprising:

means for charging the capacitors;

20 means for generating a first step of a first phase of a defibrillation pulse waveform by discharging the capacitors while the first, second and third capacitors are connected in parallel;

means for generating a second step of the first phase of the defibrillation pulse waveform by discharging the capacitors

25 while the first and second capacitors are connected in parallel and the third capacitor is connected in series; and

series.

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